national accelerator laboratory

EXP-40

April 11, 1973

ACCELERATOR EXPERIMENT: Two-turn Injection into the Booster

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Date: April 6, 1973

Several improvements to the booster and the beam diagnostics have been made since the last time multiturn injection into the booster was done. Therefore, about four hours were spent tuning the booster for two-turn injection and measuring the beam properties.

Beam Intensity at 8 GeV

The beam intensities obtained at 8 GeV under various injection conditions are listed below. Conditions (1) through (4) are results from this experiment. The beam from the linac was the usual 75-80 mA in all cases.

	8-GeV protons/Booster cycle
1) Best tuning while injecting two turns	$5.0 - 5.5 \times 10^{11}$
2) 1st turn alone with tuning for two-turn injection	$3.0 - 3.5 \times 10^{11}$
3) 2nd turn alone with tuning for two-turn injection	2.0×10^{11}
4) Best tuning for 1-turn injection using multiturn system	$3.5 - 4.0 \times 10^{11}$
5) Best tuning achieved to date with single-turn system	$5.0 - 5.5 \times 10^{11}$
6) Typical operation with single-turn system	$4.0 - 5.0 \times 10^{11}$
7) Best beam obtained previously with multiturn injection	$4.0 - 4.5 \times 10^{11}$

during First 3 msec

Decay during First 3 msec

With two-turn injection, as with the single-turn system, essentially all the beam loss occurs during the first 3 msec after injection. With the best two-turn tuning, the loss during the first 3 msec was measured for the first turn by itself and for the second turn by itself by adjusting the chopper timing. The results were as follows:

		Loss Factor
1)	Single-turn System	1.9
2)	Two-turn System	
	a) 1st turn	2.3
	b) 2nd turn	3.8

Mid F Sextupoles

Twenty-four dc sextupole correcting magnets were installed in the mid F (short) straight sections since the previous operation with multi-turn injection. The increase in 8-GeV intensity achieved is about the same as the increase obtained with the single-turn system when the sextupoles were installed. However, in both cases, other conditions were not identical before and after the sextupole installation, and it is difficult to say how much of the improvement is due to the sextupoles.

Quadrupole Corrections

The complete set of quadrupole correcting magnets is now operational, and control of all the F-quads or all the D-quads can be ganged together for shifting the tunes. This capability used in conjunction with the new system for simultaneously making continuous measurements of ν_x and ν_y makes it possible to adjust rapidly either ν_x or ν_y while keeping the other one fixed.

There is also a new control program for adjusting the amplitude and the phase of the azimuthal harmonics of the quadrupole corrections.

Most of the two-turn injection studies were done with the radial tune lowered to 6.53 while keeping the vertical tune at the usual value of 6.78. To operate at 6.53, it was necessary to put in a 13θ quadrupole correction. The beam was sensitive to changes in phase of this correction as small as 5 degrees.

Skew Quadrupoles

Very strong beats in the vertical and horizontal coherent betatron oscillations indicated strong coupling between the vertical and horizontal oscillations. The beating could be reduced somewhat by adjusting the skew quadrupole correction magnets. However, the coupling still appeared strong with the best skew quad tuning we could find. Since a large coherent radial betatron oscillation is inherent in multiturn injection, coupling can lead to serious beam loss on the vertical aperture. Indeed, right after injection, some beam loss occurred in steps at intervals of five turns. This is consistent with a vertical loss with $\nu_y = 6.78$ but would not be expected for a horizontal loss with $\nu_x = 6.53$. The radial betatron oscillation amplitude in a long straight section due to injection is as follows:

Two-Turn System*	Radial Betatron Amplitude (cm)
1) 1st Turn	0.4 - 1.1
2) 2nd Turn	1.1 - 1.8
Single-Turn System	
1) Nominal	0
2) Observed (presumably from injection errors)	0.2

It is seen that there is a correlation between the betatron amplitude and the beam decay observed during the first 3 msec. Clearly, the coupling effects at large betatron amplitude should be investigated further.

Emittance and Beam Position at Injection

Measurement of the radial emittance at the inflector for the best tuning indicated the beam width was near the value desired for the two-turn conditions we were seeking. However, the ellipse in x,x' space was tilted rather than being upright as is required for the cleanest multiturn injection.

The wire scanner at the inflector was also used to verify that the beam passing through the inflector has the design displacement from the unperturbed orbit of the circulating beam. Also, the wire scanner showed the beam in the correct radial position after making

*For injection of more than two turns, the system would be tuned so that the betatron amplitude grows more slowly with turn number.

one turn around the booster indicating that the injection orbit bump amplitude and decay rate were tuned correctly.

In this experiment, the injection system was turned to inject two turns with a radial width of 1.4 cm--the same as for matched single turn injection. The injection tuning is more critical, with the beam focussed to a smaller size, however, it would be interesting to try to see if a better match to the effective aperture of the booster can be found.

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